



The physicochemical properties of the deep eutectic solvents with triethanolamine as a major component

BILJANA S. ĐORĐEVIĆ¹, DRAGAN Z. TROTTER¹, VLADA B. VELJKOVIĆ^{1,3},
MIRJANA LJ. KIJEVČANIN², IVONA R. RADOVIĆ² and ZORAN B. TODOROVIĆ^{1*}

¹University of Niš, Faculty of Technology, Bulevar Oslobođenja 124, 16000 Leskovac, Serbia,

²Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4,
11120 Belgrade, Serbia and ³Serbian Academy of Sciences and Arts,
Knez Mihailova 35, 11000 Belgrade, Serbia

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Abstract: Different deep eutectic solvents (DESs) of triethanolamine (TEOA) and oxalic acid (OA), glacial acetic acid (AA), L-(+)-lactic acid (LA), oleic acid (OLA), glycerol (G), ethylene glycol (EG), propylene glycol (PEG), choline chloride (ChCl) or 1,3-dimethylurea (DMU) were prepared and characterized regarding their physicochemical (density, viscosity, electrical conductivity, refractive index, coefficient of volume expansion, molecular volume, lattice energy and heat capacity) properties over the temperature range of 293.15–363.15 K at 101.325 kPa. For all tested DESs, the density, viscosity and refractive index decreased with rising temperature, while the electrical conductivity increased. The temperature dependence of viscosity and electrical conductivity are described by the Vogel–Tamman–Fulcher equations. The viscosity and molar conductivity, which exhibited a linear behaviour, were correlated by the fractional Walden rule. Besides, the Fourier transform infrared spectroscopy (FTIR) was used to study the functional groups of these DESs while thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) provided the information about their stability. The tested DESs of TEOA possess desirable properties for use in various industrial processes, such as extractions, separations, chemical technology and biotechnology.

Keywords: DESs; density; viscosity; conductivity; refractive index.

INTRODUCTION

Deep eutectic solvents (DESs) are a class of two-component or three-component liquid solutions, able to dissolve many other organic and inorganic compounds. Their advantages are low cost, easy preparation, biodegradability, non-toxicity, wide liquid range, non-volatility, thermal stability and non-reactivity with water. Many different chemicals are used for their preparation, mostly sub-

* Corresponding author. E-mail: ztodorovicfle@yahoo.com
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stituted quaternary ammonium salts (usually choline chloride, ChCl) and hydrogen bond donors (HBDs) like alcohols, amides, carboxylic acids, esters, ethers and hydrated metal salts of halides, nitrates and acetates, which provide mixtures with a lower melting point than the constituents.¹

Despite the recommendation for various chemical reactions^{2,3} and the uses as a „green” solvent in cosmetic formulations, polishes, paints, inks, *etc.*, triethanolamine (TEOA) has been rarely used in the preparation of DESs. For instance, Shekaari *et al.*⁴ used ChCl:TEOA, as well as ChCl:monoethanolamine, ChCl:diethanolamine, for benzene and thiophene extraction from *n*-hexane/aromatic mixtures. The amine-based DESs, such as ChCl:monoethanolamine, ChCl:diethanolamine and ChCl:methyldiethanolamine, have already been used in CO₂ capture due to their high CO₂ dissolution capability^{5–8} and in the pretreatment of wheat straw for improving enzymatic hydrolysis.⁹ Liquid solutions based on organic solvents, particularly ionically conducting ones, have been applied for the electrolytic capacitors and batteries and in electrolytic processes of cathodic deposition of very electronegative metals.^{10,11,13} However, to the best of the authors’ knowledge, the physicochemical and thermodynamic properties of TEOA-based DESs have not been studied yet, except the ChCl-TEOA DES.^{12,13}

In order to involve the TEOA-based DESs in the future laboratory and industrial processes, it is crucial for chemists and chemical engineers to know, or be able to predict their physicochemical properties. The physical properties, such as density, viscosity, electrical conductivity and refractive index, could provide essential information on the purity of samples and the molecular interactions in the liquid, which will be useful for the design of the contacting equipment and modeling of the process.¹⁴

In this study, the physicochemical (density, viscosity, electrical conductivity, refractive index, thermal expansion coefficient, molecular volume, lattice energy, and heat capacity) properties of different DESs of TEOA as hydrogen bond acceptor (HBA) and oxalic acid (OA), glacial acetic acid (AA), L-(+)-lactic acid (LA), oleic acid (OLA), glycerol (G), ethylene glycol (EG), propylene glycol (PEG), ChCl or 1,3-dimethylurea (DMU) as HBDs were measured in the temperature range of 293.15–363.15 K at 101.325 kPa for the first time. The study was performed in the region of liquid state of binary systems (melting points of tested DESs are in the range of 283.15–313.15 K, Table S-I, Supplementary material to this paper). The fractional Walden rule was employed for understanding the relationship between molar conductivity and viscosity of the tested DESs. Additionally, the functional groups of these DESs were studied by the FTIR while the TGA and DSC analyses were performed in order to get an insight into their stability in the temperature range interesting for their industrial point of view.

EXPERIMENTAL

Materials

TEOA (99.0 %), ChCl, EG and DMU (all ≥ 98.0 %) were obtained from Sigma Aldrich. PEG and G (both Ph. Eur. grade) were provided from MeiLab (Belgrade, Serbia). AA was from Zorka (Šabac, Serbia). OLA (99.0 %) was obtained from Sigma Aldrich. OA and LA (both 99.0 %) were purchased from MosLab (Belgrade, Serbia). All chemicals were used as purchased. Information on the used chemicals is presented in Table S-I.

Preparation of DESs

DESs were prepared by combining TEOA with the selected compound at the desired molar ratio (Table S-II of the Supplementary material) on a rotary evaporator at 70 °C, as described elsewhere.¹⁵ All weight measurements were performed by a digital balance (Adam Equipment, model NBL 214e) having an accuracy of $\pm 1 \times 10^{-4}$ g. The prepared DESs were kept in the well-closed glass bottles and stored in a desiccator containing CaCl₂ before characterization to prevent moisture absorption. The water content of the dried DESs was determined by the Karl–Fischer method (Metrohm 73KF coulometer). A summary of the compositions, molar mass and water content (mass fraction), for the investigated DESs, has been presented in Table S-II while their FTIR spectra are shown in Fig. S-1 of the Supplementary material.

Physicochemical properties of DESs

All measurements were conducted at 101.325 kPa in the temperature range between 293.15 and 363.15 K after 15 min of thermostating. Density was measured using a DMA 4500 Anton Paar densitometer with the temperature measurement standard uncertainty of ± 0.005 K. Viscosity was measured by a rotational viscometer (Visco Basic Plus, ver. 0.8, Fungilab S.A., Barcelona, Spain) while a B250 ProLine conductivity meter was used for the electrical conductivity measurements. An automatic Atago refractometer A100 was applied to measure the refractive index. The densitometer was calibrated by measuring the density of double-distilled water and the results were compared to the reference values indicated in the calibration certificate of the standards. The rotational viscometer was calibrated measuring the viscosity of standard silicon oils (Fungilab) certified for each used spindle. The refractometer was calibrated measuring the certified refractive index liquids (Cargille Laboratories) and the refractive index of distilled water. The conductivity meter was calibrated by using the 0.001 M standard solution of KCl (Hach). Three replicates were carried out for each measurement of density, viscosity, conductivity and refractive index with the estimated standard uncertainty (*u*) of ± 0.5 kg·m⁻³, 5 % of the measured value, ± 0.0001 S·m⁻¹ and ± 0.00005 , respectively.

TGA and DSC analyses

The TGA and DSC analyses were done in the temperature range of 298.15–273.15 K only for the liquid DESs, namely TEOA:G, TEOA:EG, TEOA:PEG, ChCl:TEOA, as well as the ChCl-based DESs with the same hydrogen bond donors for comparison. These analyses were performed using a STA449F5 Jupiter[®], NETZSCH TGA-DSC instrument in an argon atmosphere with a total gas flow of 140 mL/min and a heating rate of 3 K/min. The calibration of the temperature and the enthalpy of the TGA-DSC instrument were carried out using the indium standard (purity > 99.999 %, Sigma Aldrich) following the instrument supplier instructions.

RESULTS AND DISCUSSIONS

Effect of temperature on density of DESs

The dependence of the density of the studied DESs on temperature is shown in Fig. 1. The experimental density values are given in Tables S-III–S-XI of the Supplementary material.

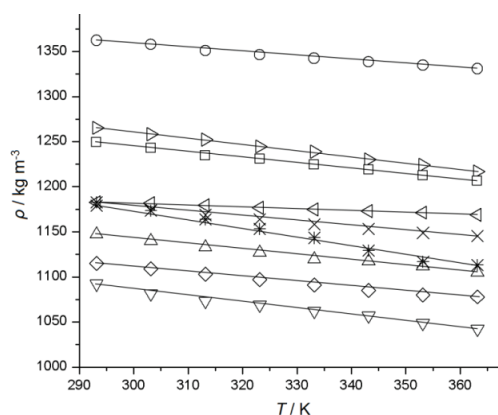


Fig. 1. Temperature dependence of the density (ρ) of the tested DESs: TEOA:OA – \circ , TEOA:AA – \triangleleft , TEOA:LA – \triangleright , TEOA:OLA – \diamond , TEOA:G – \square , TEOA:EG – \triangle , TEOA:PEG – ∇ , ChCl:TEOA – \times and TEOA:DMU – $*$.

For the temperature range of 293.15–363.15 K, the density of the tested DESs were within the range of 1362.6–1042.1 kg·m⁻³. At 313.15 K, the densities of the tested DESs follow the order: TEOA:PEG < TEOA:OLA < TEOA:EG < TEOA:DMU < ChCl:TEOA < TEOA:AA < TEOA:G < TEOA:LA < TEOA:OA.

Due to the lack of data for most of the tested TEOA-based DESs, their density was compared with the density of the DESs based on the same or similar donors. The density of DESs depends directly on the binding ability between their constitutional components. TEOA:G has a higher density than *N,N*-diethylethanol ammonium chloride:G (1:2),¹⁶ tetrapropylammonium bromide:G (1:3),¹⁷ ChCl:G (1:2)¹⁸ because TEOA has the highest number of –OH groups and makes the stronger intermolecular H-bonds network than the other DESs with G.¹⁹ For the same reason the density of TEOA:EG is higher than the density of the *N,N*-diethylethanol ammonium chloride:EG DES¹⁶ and ChCl:EG in the mole ratios of 1:1 and 1:2^{13,18,20} but lower than the density of the ChCl:triethylene glycol DES in the 1:3 mole ratio²¹ and the density of TEOA:OA is higher than that of ChCl:OA (1:1)^{12,13} and *N,N*-diethylethanol ammonium chloride:OA (3:2).²²

Although TEOA has a higher number of –OH groups than ChCl, the density of TEOA:PEG is lower than the density for ChCl:PEG (1:2).¹⁸ This phenomenon may be explained by the different molecular organization or packing of the DES according to the „hole theory”, which assumes that, after melting, the ionic material contains empty spaces arising from thermally generated local density fluctuations.¹⁹

The density of ChCl:TEOA is almost the same as those of some ChCl-based DESs.^{12,18,21,23,24} The present density values for ChCl:TEOA are lower than the values reported for ChCl:TEOA (1:2)¹² but higher than that reported for ChCl:TEOA (1:1),¹³ ChCl:monoethanolamine (1:5–8)⁶ and ChCl:diethanolamine (1:4–6).²⁵ For ChCl:TEOA, with the same mole ratio, the difference in the density values could be due to the experimental error. A decrease of the ChCl:TEOA mole ratio reduces the DES density because TEOA has a strong cohesive energy due to the presence of an important intermolecular H-bonds network and addition of ChCl was attributed to the partial rupture of this H-bonds network.¹⁹

Density was used for calculating the molecular volume (V_m), the lattice energy (U_{pot}) and the heat capacity (C_p) using the already-published equations (see Supplementary material);^{13,26} their values at 313.15 K are listed in Table S-XIII. The lattice energy of the DESs was like those of the molten salts²⁷ which explained their liquid state at this temperature. The molar volume of the TEOA:OLA (1:1) DES was the highest due to the highest molecular size of OLA. The greatest influence of the molecular size of the HBD/HBA on the molar volume was previously reported for different DESs.²⁸ Hence, the TEOA:OLA (1:1) and ChCl:TEOA (1:2) DESs had the highest heat capacity values among all tested TEOA-based DESs.

Effect of temperature on viscosity of DESs

The viscosity of DESs depends strictly on their molecular size and the strength of the hydrogen bonding in their structures. The increased hydrocarbon chain size of a DES causes an increase in the viscosity.³⁰ Also, the temperature, nature of HBD (alkyl chain length) and salt/HBD mole ratio greatly influence the viscosity of the tested DESs. The experimental viscosity values are presented in Tables S-III–S-XI.

The temperature dependence of the viscosity for the tested DESs, described by the Vogel–Tamman–Fulcher (VTF) equation, is shown in Fig. 2.

The VTF equations describing the viscosity–temperature relationship for the analyzed DESs are shown in Supplementary material. As can be seen, the viscosity decreased with increasing the temperature, probably due to the diminution of the intermolecular forces between the molecules as a result of diminishing of the hydrogen bonds in DESs.

For the temperature range of 293.15–363.15 K, the viscosity of the tested DESs lies in the range of 39.76–0.001 Pa·s. At 313.15 K, the viscosity of the tested DESs follow the order: TEOA:EG < TEOA:PEG < TEOA:G < TEOA:OA < TEOA:AA < ChCl:TEOA < TEOA:LA < TEOA:DMU < TEOA:OLA.

As for the density, due to the lack of the published data, the viscosity of the tested TEOA-based DESs was compared with the viscosity of the DESs based on the same or similar donors. The viscosity of TEOA:G is lower than those rep-

orted for *N,N*-diethylethanol ammonium chloride:G,¹⁶ tetrapropyl ammonium bromide:G (1:2)¹⁷ and ChCl:G (1:2).¹⁸ The viscosity of TEOA:EG is almost the same to those of *N,N*-diethylethanol ammonium chloride:EG¹⁶ and ChCl:EG in mole ratios of 1:1¹³ and 1:2¹⁸ while lower than that for ChCl:triethylene glycol (1:3).²¹ The change transfer via H-bonds between PEG and chloride anion from ChCl is the main reason for the larger viscosity of ChCl:PEG (1:2) relative to TEOA:PEG.¹⁸ Although the TEOA:G has a higher density than *N,N*-diethylethanol ammonium chloride:G (1:2),¹⁶ tetrapropylammonium bromide:G (1:3),¹⁷ ChCl:G (1:2)¹⁸ it has lower value for viscosity than above cited DESs. This might be due to a different molecular organization of the DESs. The viscosity of the DES depends on the chemical structure of the HBD. TEOA has a higher number of –OH groups than the other HBDs, but the factors like the alkyl chain length, the ion size and the electrostatic interactions may have a greater impact on the viscosity. At TEOA:EG the influence of these factors is smaller, so that this DES has almost the same viscosity as the DESs compared above.¹⁹

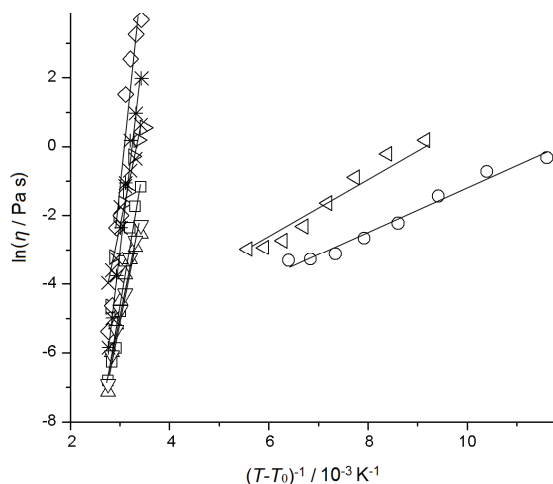


Fig. 2. VTF plot of the viscosity (η) for the following DESs: TEOA:OA – \circ , TEOA:AA – \triangleleft , TEOA:LA – \triangleright , TEOA:OLA – \diamond , TEOA:G – \square , TEOA:EG – \triangle , TEOA:PEG – ∇ , ChCl:TEOA – \times and TEOA:DMU – $*$.

The viscosity of TEOA:OA is higher than those of ChCl:OA (1:1)^{12,13} and almost the same to those for *N,N*-diethylthanol ammonium chloride:OA (3:2).²² The viscosity of ChCl:TEOA is almost the same to that of ChCl:TEOA (1:2)¹² and ChCl:diethanolamine (1:4–6)²⁵ but higher than those of ChCl:TEOA (1:1)¹³ and ChCl:monoethanolamine (1:5–8).⁶ The ChCl:TEOA viscosity is almost the same to those reported for some ChCl-based DESs^{21,23} while the viscosities of TEOA:DMU and ChCl:DMU (1:2) are similar.¹⁸ The larger viscosities of the DESs with DMU or ChCl, compared to the DESs with polyols, are the result of the differences in the strengths of hydrogen bonds. Two methyl groups in DMU also show a major effect on the viscosity of its DESs, as seen with ChCl:DMU (1:2).¹⁸ Similarly, TEOA:OLA is the most viscous DES among all the DESs with

carboxylic acids due to the largest number of methyl groups. DESs with longer alkyl chain and with carboxylic groups (TEOA:OLA; TEOA:DMU; TEOA:LA; TEOA:AA; TEOA:OA) have larger viscosities than DESs with polyols (TEOA:G; TEOA:PEG; TEOA:EG) with –OH groups. Obviously the presence of one extra carboxylic or longer alkyl chain leads to an increase in the viscosity.¹⁹ Among the polyol-based DESs, TEOA:G has the highest viscosity since G forms stronger H-bonds than the other polyol-based DESs because it has one more –OH group in the molecule than EG and PEG.¹⁹

In order to get a more detailed insight into the viscous flow and the thermodynamic functions of activation, the following expression for the viscosity of liquid mixtures is applied:¹³

$$\ln \frac{\eta V}{h N_A} = \frac{\Delta H^*}{RT} - \frac{\Delta S^*}{R} \quad (1)$$

where η is the viscosity, V is the molar volume of the eutectic mixture (calculated as the ratio of average M_{DES} and density of the mixture at desired temperature), h is the Planck's constant, N_A is the Avogadro's number, R is the universal gas constant, T is the absolute temperature, ΔH^* is the activation enthalpy change of the viscous flow and ΔS^* is the entropy change of the viscous flow. In Fig. 3, $\ln(\eta V/h N_A)$ is shown as a function of T^{-1} , Eq. (1), for each of the tested DESs. The ΔH^* and ΔS^* values were calculated from the slope and the intercept of the straight lines, respectively. Table S-XV of the Supplementary material contains the values of the thermodynamic functions of activation at 313.15 K (all tested DESs are liquid at this temperature).

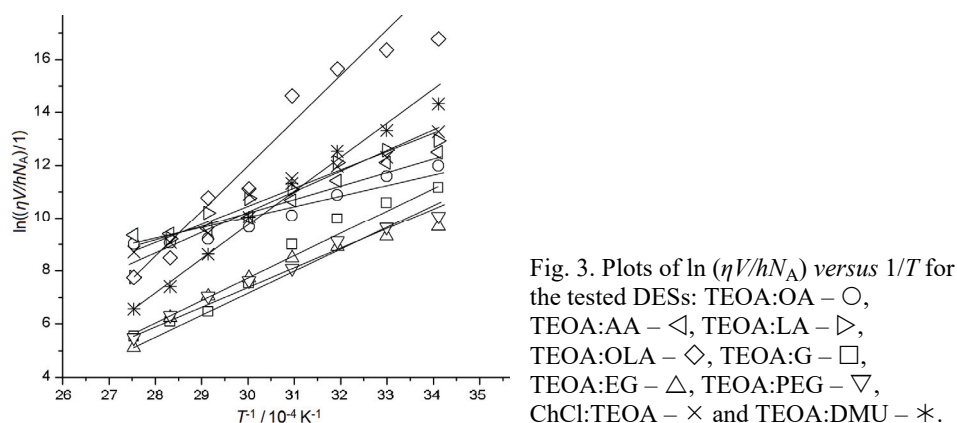


Fig. 3. Plots of $\ln(\eta V/h N_A)$ versus $1/T$ for the tested DESs: TEOA:OA – \circ , TEOA:AA – \triangleleft , TEOA:LA – \triangleright , TEOA:OLA – \diamond , TEOA:G – \square , TEOA:EG – \triangle , TEOA:PEG – ∇ , ChCl:TEOA – \times and TEOA:DMU – $*$.

Because the DESs with TEOA have the properties like the DESs with ChCl,^{12,13,18,21,23} they can serve as their suitable replacement in the possible industrial applications and various chemical reactions. However, due to the high

density and viscosity of several DESs with TEOA at room temperature, it is advisable to apply these DESs in the technological processes at temperatures higher than 313.15 K.

Effect of temperature on the electrical conductivity of DESs

The experimental electrical conductivity values, as well as the additional considerations, are presented in Tables S-III–S-XI. The electrical conductivity values for the tested DESs in the temperature range of 293.15–363.15 K lie in the range of 0.00015–9.003 S·m⁻¹. At 313.15 K, the electrical conductivities of the tested DESs are in the following order: TEOA:PEG < TEOA:G < TEOA:DMU < TEOA:EG < TEOA:OLA < TEOA:LA < TEOA:AA < TEOA:OA < ChCl:TEOA.

TEOA:G has less electrical conductivity compared to the literature values for the ChCl:G (1:2).^{18,24} The same case is for the TEOA:EG, which electrical conductivity is lower than those reported for ChCl:EG, in the mole ratios of 1:1¹³ and 1:2²⁰ but higher than that of the ChCl:triethylene glycol (1:3) DES.²¹ The electrical conductivity of TEOA:PEG is lower than that of ChCl:PEG (1:2).¹⁸ The TEOA:OA electrical conductivity is lower than that of ChCl:OA (1:1)¹² and almost the same to that of *N,N*-diethylethanol ammonium chloride:OA (3:2).²² The electrical conductivity of ChCl:TEOA is higher than the values reported for ChCl:TEOA (1:2)¹² and ChCl:TEOA (1:1).¹³ The electrical conductivity of TEOA:DMU is lower than that of ChCl:DMU (1:2).¹⁸

The conductivity of DESs is affected by both the mobility and number of charged species. DESs with relatively high viscosities exhibit poor ionic conductivities. In relation to all tested DESs TEOA:G and TEOA:PEG had the lowest viscosity, so it is logical that they have the highest conductivity.¹⁹ Generally, all TEOA-based DESs have lower conductivity compared to the ChCl-based DESs because high weight ratio of the salt in ChCl contributes to the higher number of charge carriers of the ChCl relative to the TEOA. Also, the larger size of the TEOA compared to the ChCl results in both reduced ion mobility and lower conductivity.¹⁹

The temperature dependence of the electrical conductivity of the tested DESs described by the VTF equation is shown in Fig. 4.

Molar conductivity and viscosity relationship

The temperature dependence of the molar conductivity of the tested DESs described by the VTF equation is shown in Fig. 5 (additional considerations are given in Supplementary material).

The Walden rule is very useful for the DES categorization. Data for the dilute aqueous 0.01 M KCl solution is used for drawing the „ideal” reference line,³¹ which is representative for the independent ions with no interionic interactions.²⁹ Solvents with the ability to form ions are located very close to the

reference line, while the solvents with this lower ability are further away.^{21,30} As it can be seen in Fig. 6, the tested DESs belong to the category of the „subionic liquids”, indicating the non-ionic structure of the DESs.

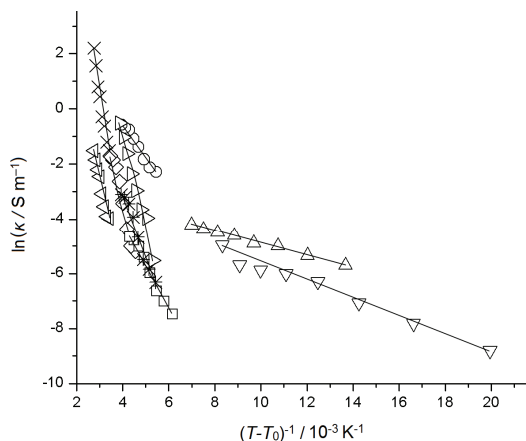


Fig. 4. VTF plot of the electrical conductivity (κ) for the DESs: TEOA:OA – \circ , TEOA:AA – \triangleleft , TEOA:LA – \triangleright , TEOA:OLA – \diamond , TEOA:G – \square , TEOA:EG – \triangle , TEOA:PEG – ∇ , ChCl:TEOA – \times and TEOA:DMU – $*$.

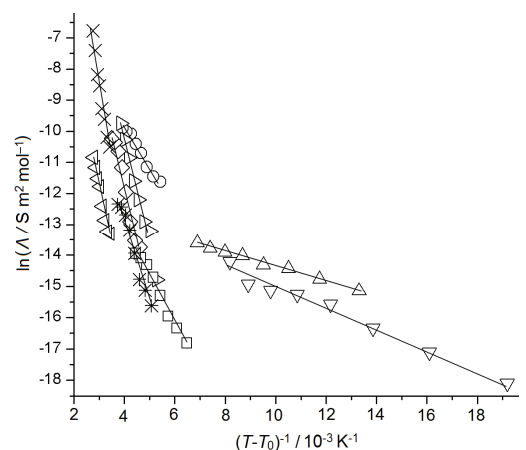


Fig. 5. VTF plot for the molar conductivity (κ) of the tested DESs: TEOA:OA – \circ , TEOA:AA – \triangleleft , TEOA:LA – \triangleright , TEOA:OLA – \diamond , TEOA:G – \square , TEOA:EG – \triangle , TEOA:PEG – ∇ , ChCl:TEOA – \times and TEOA:DMU – $*$.

Effect of temperature on the refractive index of DESs

The linear dependence of the refractive index of the studied DESs on temperature is shown in Fig. 7 (additional considerations are given in Supplementary material).

As expected, the refractive index of the pure DESs decreases linearly with the increase of temperature depending on the structure and the nature of their components that are combined with TEOA. When they are heated, the molecules are moving faster, which results in the density and refractive index reduction. The refractive index of the tested DESs in the temperature range of 293.15–363.15 K lies within the range of 1.4991–1.4137. At 313.15 K, the refractive

index of the tested DESs follows the order: TEOA:OLA < TEOA:PEG < TEOA:EG < TEOA:G < TEOA:AA < TEOA:OA < TEOA:LA < ChCl:TEOA < TEOA:DMU. The refractive index values of these DESs agrees to those of the other DESs with ChCl.¹⁴ The experimental refractive index values are represented in Tables S-III–S-XI as well as additional considerations in the Supplementary material.

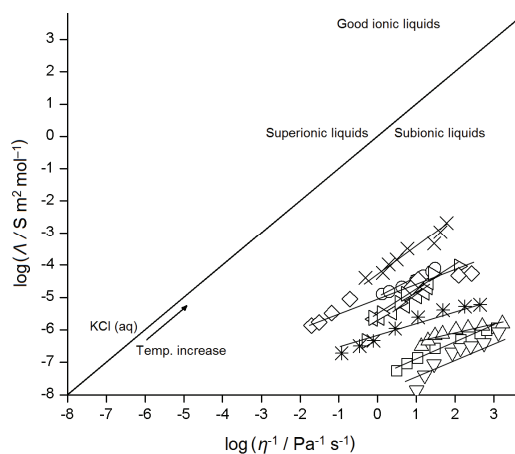


Fig. 6. Walden plots for the tested DESs: TEOA:OA – ○, TEOA:AA – ◁, TEOA:LA – ▷, TEOA:OLA – ◇, TEOA:G – □, TEOA:EG – △, TEOA:PEG – ▽, ChCl:TEOA – × and TEOA:DMU – *.

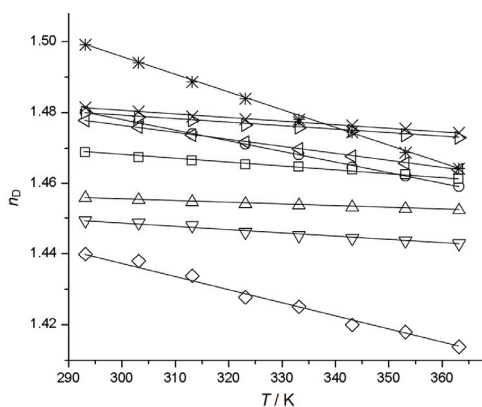


Fig. 7. Temperature dependence of the refractive index (n_D) of the tested DESs: TEOA:OA – ○, TEOA:AA – ◁, TEOA:LA – ▷, TEOA:OLA – ◇, TEOA:G – □, TEOA:EG – △, TEOA:PEG – ▽, ChCl:TEOA – × and TEOA:DMU – *.

The refractive index of TEOA:G is almost the same to those of *N,N*-diethyl-ethanol ammonium chloride:G,¹⁶ tetrapropylammoniumbromide:G (1:2)¹⁷ and ChCl:G (1:2).¹⁸ Almost the same values of the refractive index of TEOA:PEG and ChCl:PEG (1:2),¹⁸ and ChCl:TEOA, ChCl:monoethanolamine⁶ and ChCl:diethanolamine (1:4–6)²⁵ are related to their similar molecular structures. The refractive index of TEOA:DMU and ChCl:DMU (1:2) are almost the same.¹⁸

TGA and DSC analyses

The TGA and DSC curves of the selected TEOA- and ChCl-based DESs with the same donors are shown in Fig. S-2 of the Supplementary material. The TGA and DSC analysis were performed over the temperature range of 298.15–373.15 K. Since the investigated systems are liquids, it is understandable that no melting temperature have been observed in the DSC traces. Furthermore, even though the first derivatives of DSC and TGA curves show some peaks at certain temperatures, they cannot be related neither to some special changes in the molecular structure of the mixtures, nor to the phase transition. They indicate the stability of the DESs within the tested temperature range, which is favourable for their potential application in the industry.

CONCLUSIONS

The physicochemical properties (density, viscosity, electrical conductivity and refractive index) of several TEOA-based DESs were measured in the temperature range of 293.15–363.15 K at 101.325 kPa. The thermal expansion coefficient, the molecular volume, the lattice energy and the heat capacity of these DESs were calculated using the density and the viscosity data. The Vogel–Tammann–Fulcher equations were used to characterize the temperature dependence of the viscosity and the electrical conductivity for the investigated DESs. While the density, the viscosity the and refractive index of the tested DESs decrease with the increasing temperature, their electrical conductivity rises. According to the Walden rule, these DESs are classified as „subionic liquids”. Among these DESs, those with polyols and lower carboxylic acids exhibit low viscosities at lower temperatures, so they can serve as solvents in possible industrial applications and various chemical reactions, while it is recommended to heat up DESs with oleic acid and DMU before use and apply them at temperatures higher than 313.15 K. The FTIR analysis showed no chemical changes occurred during their preparation, while TGA and DSC analyses confirmed the stability of the DESs within the tested temperature range, which is favourable for their potential application in the industrial processes, such as extractions of different compounds, separations, chemical and biochemical technology.

SUPPLEMENTARY MATERIAL

Additional data and considerations are available electronically from <http://www.shd.org.rs/JSCS/>, or from corresponding author on request.

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ИЗВОД
ФИЗИЧКО–ХЕМИЈСКЕ И ТЕРМОДИНАМИЧКЕ ОСОБИНЕ ЕУТЕКТИЧКИХ
РАСТВОРАЧА СА ТРИЕТАНОЛАМИНОМ

БИЉАНА С. ЂОРЂЕВИЋ¹, ДРАГАН З. ТРОТЕР¹, ВЛАДА Б. ВЕЉКОВИЋ^{1,3}, МИРЈАНА Љ. КИЈЕВЧАНИН²,
ИВОНА Р. РАДОВИЋ² И ЗОРАН Б. ТОДОРОВИЋ¹

¹Технолошки факултет, Универзитет у Нишу, Булевар ослобођења 124, 16000 Лесковац,

²Технолошко–металушки факултет, Универзитет у Београду, Карнегијева 4, 11000 Београд и

³Српска академија науке и уметности, Кнез Михајлова 35, 11000 Београд

У овом раду направљени су еутектички растварачи триетаноламина са оксалном киселином, глацијалном сирћетном киселином, млечном киселином, олеинском киселином, глицеролом, етилен гликолом, пропилен гликолом, холин-хлоридом и 1,3-диметилуреом. Свим еутектичким растварачима одређене су физичко–хемијске особине (густина, вискозитет, електрична проводљивост и индекс рефракције) и израчунате термодинамичке особине (коэффициент запреминског ширења, моларна запремина, енергија решетке и топлотни капацитет) у функцији од температуре у опсегу 293,15–363,15 К на 101,325 кРа. Код свих припремљених еутектичких растварача густина, вискозитет и индекс рефракције опадају са порастом температуре док електрична проводљивост расте. Ове температурне зависности вискозности и електричне проводљивости су описане Vogel–Tamman–Fulcher једначином. Вискозитет и моларна проводљивост, који показују линеарно понашање, били су у корелацији са фракционим Walden правилом. Инфрацрвена спектроскопија са Фуријеовом (Fourier) трансформацијом коришћена је за проучавање функционалних група еутектичких растварача, док су термогравиметријска анализа и диференцијална скенирајућа калориметрија коришћене за одређивање њихових стабилности. Утврђено је да анализирани еутектички растварачи поседују својства која им омогућавају примену у различите индустријске процесе попут екстракције, сепарације, хемијске технологије и биотехнологије.

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